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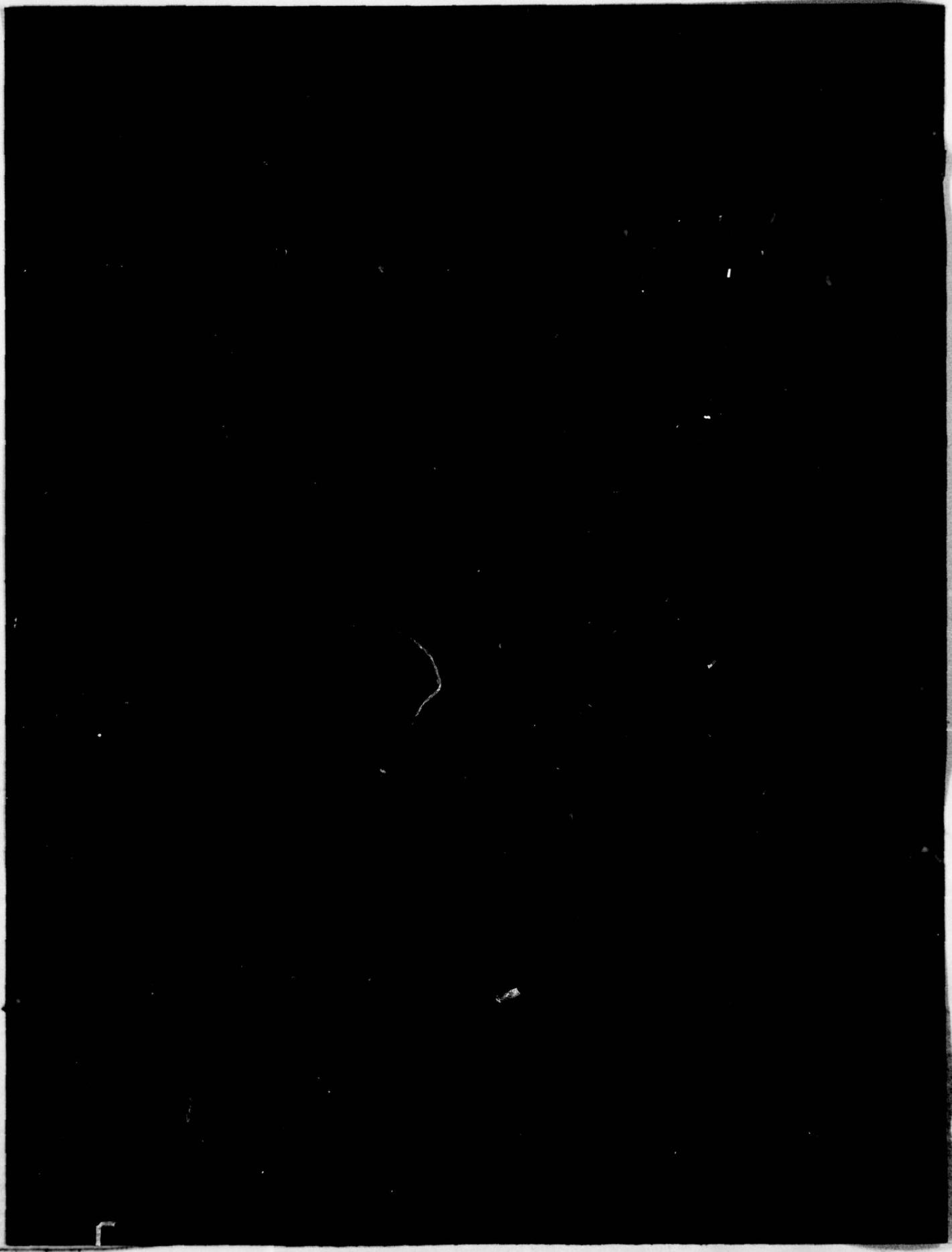
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report evaluates both the hardware and software of the Texas Instruments Advanced Scientific Computer (TIASC) at the Naval Research Laboratory in terms of their applicability to numerical fluid dynamics calculations. DTNSRDC users access this computer via an on-site Remote Job Entry Terminal. The "pipelined" central processor of the TIASC has been found particularly valuable in numerical fluid dynamics work, especially when combined with the graphics capabilities available at DTNSRDC. Several examples			

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**Item 20. ABSTRACT (cont.)**

of fluid dynamics problems which were successfully solved using the TIASC are given.



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## FOREWORD

This DTNSRDC report, which evaluates the TI-ASC computer located at the Naval Research Laboratory, may benefit from a few preliminary words of background information concerning the Navy's changing philosophy in the use of laboratory computing facilities.

The Navy Laboratory Computing Committee (NLCC), established by SECNAVINST 5420.176 in October 1974, has been influential in fostering a cooperative environment in which computer resources are directly shared among the various Naval Laboratories. This direct sharing is physically made possible by computer and communications technology which links together geographically separated computer facilities through the use of telephone lines and either desk-top terminals or remote job entry batch terminals. The NLCC is in the process of setting up a special Navy Laboratory Computer Network (NALCON) which will make the major computer resources of the Navy Laboratory Computing Centers available to scientists and engineers at all the laboratories on a more efficient and less costly basis than is currently possible. Moreover, since NALCON will use the ARPANET (the Advanced Research Projects Agency Network) operated by the Defense Communications Agency, naval research personnel will also have access to other non-Navy computer facilities available on the ARPANET. Thus, the interactive, desk-top terminals now in use at DTNSRDC will provide access to a variety of computer and software aids which will augment the powerful CDC-6000 Series computer systems at the Carderock Laboratory.

Since no naval laboratory can support all the facilities which it may need from time to time to fulfill changing research needs, a resource-sharing capability is highly desirable and can be both efficient and cost-effective. One example of successful resource sharing is provided by DTNSRDC's current use of the TI-ASC computer to solve numerical fluid dynamics problems, including free surface potential flow, viscous flow, and discrete vortex flow analysis. It is noteworthy that the term "resource sharing" in this instance means combining the computing power available at both NRL and Carderock to take advantage of the best features of each facility for solving these challenging problems. The

manner in which this remote coupling of hardware and software at the two different sites was achieved is described in Mr. Morawski's report along with an evaluation of the various components and services used by our research team.

Joanna W. Schot, Head  
Numerical Fluid Dynamics Branch

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## ABSTRACT

This report evaluates both the hardware and software of the Texas Instruments Advanced Scientific Computer (TIASC) at the Naval Research Laboratory in terms of their applicability to numerical fluid dynamics calculations. DTNSRDC users access this computer via an on-site Remote Job Entry Terminal. The "pipelined" central processor of the TIASC has been found particularly valuable in numerical fluid dynamics work, especially when combined with the graphics capabilities available at DTNSRDC. Several examples of fluid dynamics problems which were successfully solved using the TIASC are given.

## I. INTRODUCTION

The Texas Instruments Advanced Scientific Computer #7 (TIASC) is a large-scale digital computer located at the Naval Research Laboratory. Its unique central processor architecture, massive central memory, and availability to the Navy community via interactive terminals make it attractive to computer users who run large numerical codes. Personnel in the Numerical Fluid Dynamics Branch investigated the practicality of using the TIASC soon after it became available, and have since used it as their primary "number cruncher" for many applications.

The inability to run programs interactively on the TIASC has led to a coupling of NRL and DTNSRDC computer power. For example, the development of a large computer program might involve some or all of the following steps:

- 1) Building program text on the TIASC using interactive terminals located at DTNSRDC.

- 2) Using EDIT<sup>1</sup> (a program developed by Code 1843 which is available at both NRL and DTNSRDC) to manage the program's "source", "object", and "execute" files.
- 3) Generating the program input on the DTNSRDC CDC-6000 series equipment.
- 4) Transferring the input to the TIASC by magnetic tape or punched cards through the DTNSRDC Remote Job Entry Terminal.
- 5) Running the program on the TIASC.
- 6) Transferring program results to the DTNSRDC CDC-6000 series computers by magnetic tape or punched cards through the DTNSRDC Remote Job Entry Terminal.
- 7) Using the extensive interactive graphics capability available at DTNSRDC<sup>2,3,4,5,6</sup> to display the computed results in a usable fashion.

This procedure allows users to take advantage of both machines' strong points without paying an undue penalty for their weak points. The

<sup>1</sup> Morawski, Paul, "EDIT: A FORTRAN Program Maintenance System for the Texas Instruments ASC-7," Computation, Mathematics, and Logistics Department, Departmental Report CMLD-77-07, March 1977.

<sup>2</sup> Morawski, Paul, "XYZPLOT: A Three-Dimensional Graphics Package for Fluid Dynamics Calculations," Computation and Mathematics Department, Departmental Report CMD-15-75, August 1975.

<sup>3</sup> Marquardt, Mary Beth, "ENGPLOT: An Engineering Plotting Program," Computation and Mathematics Department, Technical Note CMD-9-74, February 1974.

<sup>4</sup> Kelly, Barbara M. and Marquardt, Mary Beth, "Interactive Helicopter Design: Geometry Package User's Manual," Computation and Mathematics Department, Departmental Report CMD-28-74, September.

<sup>5</sup> Haas, Melvin E., "Interactive IMAGE Display System," Computation, Mathematics, and Logistics Department Report (in preparation).

<sup>6</sup> Marquardt, Mary Beth, "CONTOUR II: A Revised Surface Fitting and Mapping Program," Computation, Mathematics, and Logistics Department, Departmental Report CMLD-76-26, October 1976.

NALCON (Navy Laboratory Computer Network) long-range plans for file exchange will further expedite this process by automating steps 4 and 6.

This report briefly discusses many of the current strengths and weaknesses of the TIASC, and through examples shows how its strong points have been exploited to further the DTNSRDC computational power in numerical fluid dynamics.

## II. NRL TIASC FACILITIES AVAILABLE TO THE DTNSRDC USER

### TIASC HARDWARE CHARACTERISTICS

#### Central Processor and Vectorization

The distinguishing feature of the TIASC is its dual pipeline Central Processor (CP). A pipeline processor is one which can perform a calculation while simultaneously fetching operands for the next operation and storing results from the last calculation. These operations are said to overlap. The TIASC accomplishes this type of overlap when it operates on arrays in its so-called vector mode. (In this context an array need not be stored in contiguous memory locations; it may instead be scattered through memory in some well-ordered manner.) In vector mode, the Memory Buffer Unit (MBU) fetches sets of eight operands and buffers them into the Arithmetic Unit (AU). The MBU also buffers results produced by the AU into arrays in central memory. This capability insures that the Arithmetic Unit (which has its own eight internal levels of overlap) never waits for an operand to be fetched or a result to be stored. Once a vector operation is begun the Central Processor can effectively produce a maximum of one result per clock cycle, since new operands are being fetched at the same time that results are being stored. Most of the commonly used operations (e.g., double-precision floating-point arithmetic) require somewhat more than one clock cycle per result, but still execute quite rapidly. The NRL TIASC has two of these "pipelines", which may operate simultaneously and independently during the execution of one program. This mechanism gives the TIASC maximum operational rates of over 16 mflops for double precision addition and over 8 mflops for

double precision multiplication (1 mflop = 1 million floating point operations per second).

The user seldom interacts directly with the hardware aspects of "vectorization". A special FORTRAN compiler is available to recognize code which may be implemented using vector instructions. The requirement that the operands and results be stored "in some well-ordered manner" is seldom a problem. For example, if one wants to operate on a matrix row by row or column by column, the FORTRAN method for mapping a two-dimensional array into memory provides enough regularity between adjacent elements to make vectorization possible.

Certain code cannot be executed in vector mode on the TIASC, for example, the following FORTRAN DO-loop, which illustrates a calculation similar to those often used in solving finite-difference approximations to partial differential equations. It stores  $(X_{i-1}+X_{i+1})/2$  into  $X_i$  for  $i = 2$  to  $99$ .

```
DO 100 I=2,99
100 X(I)=.5*(X(I-1)+X(I+1))
```

If  $I=9$  at some stage of the calculation, one of the required operands would be  $X(I-1)=X(8)$ . The proper value of  $X(8)$  would be the one which was stored during the previous iteration, i.e., when  $I=8$ . However, since vectorization would overlap the fetching and storing operations,  $X(8)$  might be fetched for the  $I=9$  computation before the updated value of  $X(8)$  was stored for the  $I=8$  computation.

The following FORTRAN code performs a roughly equivalent calculation. It first stores  $(X_{i-1}+X_{i+1})/2$  into  $X_i$  for  $i=2$  to  $98$  in steps of 2. Then it stores  $(X_{i-1}+X_{i+1})/2$  into  $X_i$  for  $i=3$  to  $99$  in steps of 2.

```
DO 50 I=2,98,2
50 X(I)=.5*(X(I-1)+X(I+1))
DO 100 I=3,99,2
100 X(I)=.5*(X(I-1)+X(I+1))
```

This method (the so-called Red-Black scheme) will vectorize since neither of its loops attempts to calculate using a value from a previous iteration.

Algorithms which depend on indirect addressing (e.g., variables having subscripted subscripts) may sometimes be vectorized by the use of special coding. Coding involving linked lists (i.e., ordered lists whose ordering is stored in separate link arrays) should not be expected to vectorize. Also FORTRAN DO loops containing IF statements may not vectorize.

All these special cases of unvectorizable FORTRAN code will compile and execute in scalar mode. Nearly all programs compile into a mixture of scalar and vector code. Since scalar code executes considerably more slowly than corresponding vector code, algorithms and programs should be written in such a way that they will vectorize.

#### Central Memory

The TIASC presently has 1 million 32-bit words of central memory. Of this, approximately 700,000 words are available for user programs. A set of Protect Registers is used to define the region of memory which a given program may access and to protect the integrity of that program's memory area. There are plans to expand the memory capacity first to 2 million words, then to 4 million words.

#### Secondary Storage

Two types of disc units are available on the TIASC. The Head Per Track (HPT) units have fixed read/write heads, a maximum transfer rate of 491,000 words per second, and a storage capacity of 25 million words each. These units are used primarily for program scratch files and often-used system files. The Positioning Arm Disc (PAD) units have a maximum transfer rate of 200,000 words per second and a storage capacity of 20 million words. These units are used primarily for cataloged files. User programs currently may use up to 24 million words of disc storage.

The TIASC has both 7- and 9-track tape transports which operate at all the standard recording densities. When a tape file is requested, it is immediately staged to a disc file, where it may be accessed by the requesting program. Similarly, programs write tapes by first writing disc files and then requesting, by control card statements, that the file be transferred to tape. This procedure reduces the central processor

wait time, especially for jobs requiring large amounts of input from or output to tapes.

#### Supporting Minicomputers

Conversational terminals and Remote Job Entry Terminals are supported by two independent minicomputers called Data Concentrators. Their independence prevents the overall system from being adversely affected should one or both concentrators fail.

The entire hardware system is supervised by the Peripheral Processor. This processor (which is actually eight minicomputers sharing certain resources) executes the operating system, performs services for the Central Processor, and generally controls the system, allowing the Central Processor to be dedicated primarily to executing user programs.

#### Failures

The TIASC hardware seems relatively reliable (from a user's standpoint) with two exceptions. 1) Physical damage to the disc units sometimes causes cataloged files to be lost. When this happens, the entire cataloged file system is restored from backup tapes made at the end of the previous work day, and computer charge credit is sometimes given to users whose work was ruined by the failure. 2) Power outages cause a considerable amount of down time due to hardware failures.

### AVAILABLE SOFTWARE

#### General Purpose Operating System

The most visible piece of software on the TIASC is its operating system, the General Purpose Operating System (GPOS). Users communicate with the operating system via the Job Specification Language (JSL), which is quite similar to IBM's Job Control Language (JCL). Users accustomed to CDC's SCOPE or NOS/BE control card languages will find that JSL is not as straightforward, primarily with respect to describing file characteristics.

JSL does have strong points, however. One is that users may branch around selected control cards by setting values of certain JSL variables from within their own FORTRAN programs.

Another strength of JSL is its macro programming capability. The JSL MACRO language allows the user to write programs which selectively generate JSL statements. This feature allows often-used sequences of control cards to be automated. However, the MACRO language is low level and is not easy to use. EDIT<sup>1</sup> (described on page 9) is one example of a macro program written in the JSL MACRO language.

Names of cataloged files are managed in a tree structure, permitting users to define a hierarchical organization with their file names. For example, all files associated with a given project may be cataloged beneath the same node in the user's tree structure. Cataloged files reside either on disc or on tape. Alert users may choose to catalog several files on the same tape and realize a corresponding reduction in storage charges.

#### Terminal Operating System

The interactive keyboard system is supported by the Terminal Operating System (TOS), which runs on one of the minicomputers (Data Concentrators). TOS allows users to load files from the TIASC and then edit them using a text editor. TOS may be used to submit control cards to the TIASC for execution and to submit entire jobs to the input queue. Since the Data Concentrator is independent of the TIASC, the user may continue text editing even if the TIASC goes down for a short period. TOS is becoming more and more reliable and response is very good.

#### FORTRAN Compilers

Texas Instruments supplies two FORTRAN compilers for the TIASC. The FX compiler runs extremely fast and performs no optimization. It is good for debugging, since it provides tracebacks when programs terminate abnormally and is inexpensive to use. The NX compiler runs much more slowly and produces faster object code. It can recognize many loops which may be executed in vector mode, and it can re-order scalar code to achieve better instruction overlap. The NX compiler also supplies an optimization summary which allows the user to see which code did and did not vectorize, and why.

Both compilers have bugs and sometimes generate incorrect object code. These errors usually surface from the NX compiler when it performs its optimization function. A compiler error is usually obvious because the program then generates wildly incorrect results. In comparatively few cases compiler bugs introduce only subtle errors. Fewer bugs surface and best optimization occurs when the compilers are presented with straightforward code. New releases of the compilers generally contain fewer and fewer bugs.

#### RATIONAL FORTRAN Preprocessor

A structured programming language called RATFOR<sup>7</sup> is used by many DTNSRDC users. The RATFOR processor generates a file containing standard FORTRAN as its output. This file is then used as input to one of the FORTRAN compilers. The TIASC version of RATFOR is completely compatible with the DTNSRDC version. RATFOR both reduces coding time and minimizes programming errors.

#### File Updating Programs

A file editing program called CIFER (Card Image File Editor) may be used to perform certain file maintenance tasks (copy, punch, etc.) as well as to update files. When CIFER is used for updating, lines of text are physically deleted from the file and no historical information is kept to identify lines which have been added or deleted. SMS (Source Management System) on the other hand deactivates lines by setting internal indicators which flag those lines as inactive. Deactivated lines may be restored later simply by reactivating them by using an SMS directive. Alpha-numeric card sequence numbers are used to reflect the date on which a card was added. This method is more appropriate for maintaining large programs and program systems of the type written for numerical fluid dynamics work. However, SMS is not used by most TIASC users at NRL (they use CIFER), and therefore fewer qualified people are available to assist new SMS users. This has not been a problem since SMS is remarkably similar to a heavily used CDC program called UPDATE.

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<sup>7</sup> RATIONAL FORTRAN preprocessor, see: Kernighan and Plauger, "Software Tools," Addison-Wesley (1976). Consult DTNSRDC Code 1843, Numerical Fluid Dynamics Branch, (702) 227-1933 for local modifications to RATFOR.

### The EDIT Program Maintenance System

A complete FORTRAN/RATFOR program maintenance package called EDIT is used on the DTNSRDC CDC-6000 computers.\* Since EDIT is built around CDC UPDATE, and UPDATE is equivalent to TI SMS, a MACRO program, also called EDIT<sup>1</sup>, was written to serve the same function on the TIASC. EDIT is used to automatically update and provide backup versions of source libraries, object libraries, and load modules, all stored on cataloged files. Using EDIT on the TIASC can save programmers from writing up to 80 JSL statements to perform the same task. The benefits are obvious: DTNSRDC EDIT users may become active on the TIASC by learning a minimum of JSL, EDIT provides a standard method for storing, updating, and accessing programs, and EDIT does not make capricious mistakes (as programmers do). The TIASC version of EDIT is fully documented<sup>1</sup>.

### Mathematical Routines

A package of mathematical routines is available to perform functions such as matrix inversion. Although these routines usually work on the TIASC, few of them are written to take advantage of the TIASC's vector capabilities. As a result they are not very efficient. The NRL User Services Section (Code 4222) is working to improve this situation by assembling its own Scientific Program Library (SPL). Most of the SPL routines are donated by users and are written especially for the TIASC. Only carefully documented routines are put in this library.

### Plotting Routines

DISPLAA (Display Integrated Software System and Plotting Language), Tektronix Plot 10, and a library of low-level plotting routines are available to generate plot files on the TIASC. DTNSRDC users have not used any of these products, since strong in-house graphics support is available at DTNSRDC.

### Failures

Adequate documentation is available for all the software mentioned. Software failures sometimes occur, usually during FORTRAN compilation.

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\* The DTNSRDC version of EDIT was developed by Mr. Mel Haas of DTNSRDC Code 1843 in 1972.

## DTNSRDC REMOTE JOB ENTRY TERMINAL

DTNSRDC users access the TIASC via a Remote Job Entry (RJE) terminal. The nucleus of the RJE is a TI-980 minicomputer with a dedicated phone line to the Data Concentrator at the TIASC. The TI-980 serves to interface and control a card reader, card punch, line printer, nine-track tape drive, and an 11-inch Calcomp 565 drum plotter, all located at DTNSRDC. The tape drive is used to copy tapes at DTNSRDC onto tapes at NRL, and vice-versa, thus providing an indirect method of exchanging data between sites.<sup>8</sup> The RJE hardware at DTNSRDC is generally reliable, and the overall service is adequate. The present location of the RJE terminal limits its availability, since the room is accessible for only 8 1/2 hours a day. A further bottleneck is created by the procedure of logging jobs out by hand to collect accounting information.

## NRL USER SERVICES

The User Services Section (NRL Code 4222) performs the primary support function for the TIASC. It offers classes on TIASC usage and also publishes and distributes bulletins reflecting the current status of the overall system. User meetings, held regularly, include presentations to keep users informed of the system status, and provide users with an opportunity to make their opinions known. It is sometimes difficult for outside users to make intelligent decisions about attending these meetings, since the agenda is not always released very far in advance. Nevertheless NRL Code 4222 has provided encouragement and good support to DTNSRDC personnel who use the TIASC.

User Services also operates a consultant's desk for TIASC users. Outside user's interaction with this service is limited to telephone contacts with the consultant on duty. Although this method of providing users with assistance has promise, the results vary from good to marginal. Perhaps this deficiency will be eliminated as NRL expands its staff of qualified consultants.

<sup>8</sup> Morawski, Paul, "Notes on Data File Exchange between the NRL TIASC and the DTNSRDC CDC-66/6700," DTNSRDC Computation, Mathematics, and Logistics Department, Technical Memorandum, in preparation.

### III. APPLICATIONS

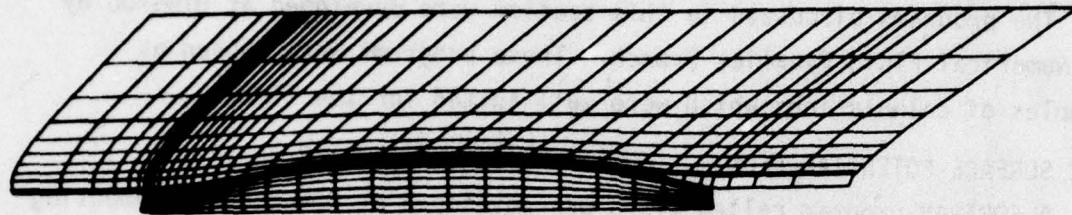
The programs discussed in this section were developed at DTNSRDC by the Numerical Fluid Dynamics Branch. These programs were chosen as examples of calculations which were well suited for the TIASC.

#### FREE SURFACE POTENTIAL FLOW

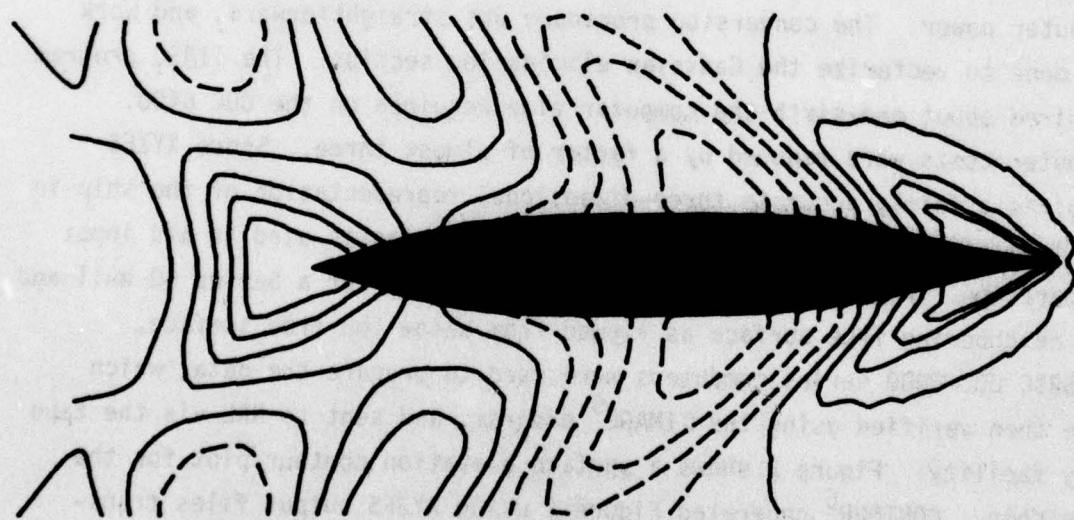
A FORTRAN program called XYZFS was developed at DTNSRDC for computing the three-dimensional, steady state potential flow about a ship-like body in or near the free surface<sup>9</sup>. The program solves the Laplace equation using a source density distribution over both the body surface and a local portion of the free surface. A linearized free surface boundary condition is used. The heart of the calculation is a Gaussian elimination performed on a full matrix of orders up to 568. The program was converted from the DTNSRDC CDC-6000 series equipment to the TIASC when it became apparent that practical problems would require considerably greater computer power. The conversion procedure was straightforward, and work was done to vectorize the Gaussian elimination section. The TIASC program required about one-sixth the computer time required on the CDC 6400. Computer costs were reduced by a factor of almost three. Since XYZFS requires a fairly accurate three-dimensional representation of the ship in the form of quadrilateral panels, computer graphics is used to aid input preparation. Figure 1 shows such a representation for a Series 60 hull and the neighboring free surface as viewed from below the free surface. DTNSRDC CDC-6000 series computers were used to prepare the data, which were then verified using the TIMAGE<sup>5</sup> program, and sent to NRL via the tape copy facility. Figure 2 shows a surface elevation contour plot for the same ship. CONTOUR<sup>6</sup> generated Figure 2 using XYZFS output files transmitted to DTNSRDC by tape.

A user's manual for XYZFS will soon be available and will make the program available to the Navy community. Since the program is meant to be

<sup>9</sup> Dawson, C.W., "A Practical Computer Method for Solving Ship Wave Problems," presented at the Second International Conference on Numerical Ship Hydrodynamics, 19-21 September 1977.



**Figure 1 - Panel Arrangement for Series 60 Hull  
as Viewed from below the Free Surface**



**Figure 2 - Surface Elevation Contour Plot  
about Series 60 Hull  
(Aerial View)**

user-oriented, a set of macro programs was written to control the execution of XYZFS. The macros automatically generate all the control cards necessary to execute XYZFS when the user supplies one control card. Designing program systems in this manner enhances their usefulness, since program users need not learn a great deal about irrelevant control cards.

#### HYDRODYNAMIC NOISE GENERATION

A RATFOR program called VORTEX<sup>10</sup> was written to calculate the hydrodynamic noise generated by a two-dimensional shear layer. The layer was modeled with discrete vortices, and the calculation involved solving  $2N$  coupled non-linear ordinary differential equations where  $N$  was as large as 256. The TIASC was chosen both for its central memory capacity and its vectorization. Efforts were made to insure that the program would vectorize. The resulting computer charges were as low as one-sixth those for running the same problem on the DTNSRDC CDC-6000 series computers. Figure 3, a plot obtained at DTNSRDC using TIMAGE<sup>5</sup>, was generated by VORTEX and shows the interaction of 256 discrete vortices over a period of time.

#### MOVING PRESSURE DISTRIBUTION TO MODEL A SURFACE EFFECT SHIP

A RATFOR program was written to calculate the hydrodynamic forces and surface elevations due to a pressure distribution between two vertical plates translating across the free surface. This model is used to simulate a surface effect ship. The program solved Laplace's equation by a fast Laplace solver employing embedding techniques. The TIASC was chosen both for speed and memory requirements. Several compiler bugs were encountered during the development of this program, but they were not difficult to program around. Three-dimensional surface elevations behind the translating plates are shown in Figure 4. TIMAGE<sup>5</sup> was used to generate this figure, from data transferred by punched cards.

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<sup>10</sup> Grabowski, Walter J. and Telste, John G., "A Discrete Vortex Simulation of a Two-Dimensional Shear Layer with Prediction of the Hydrodynamic Noise," Computation, Mathematics, and Logistics Department, Departmental Report, in preparation.

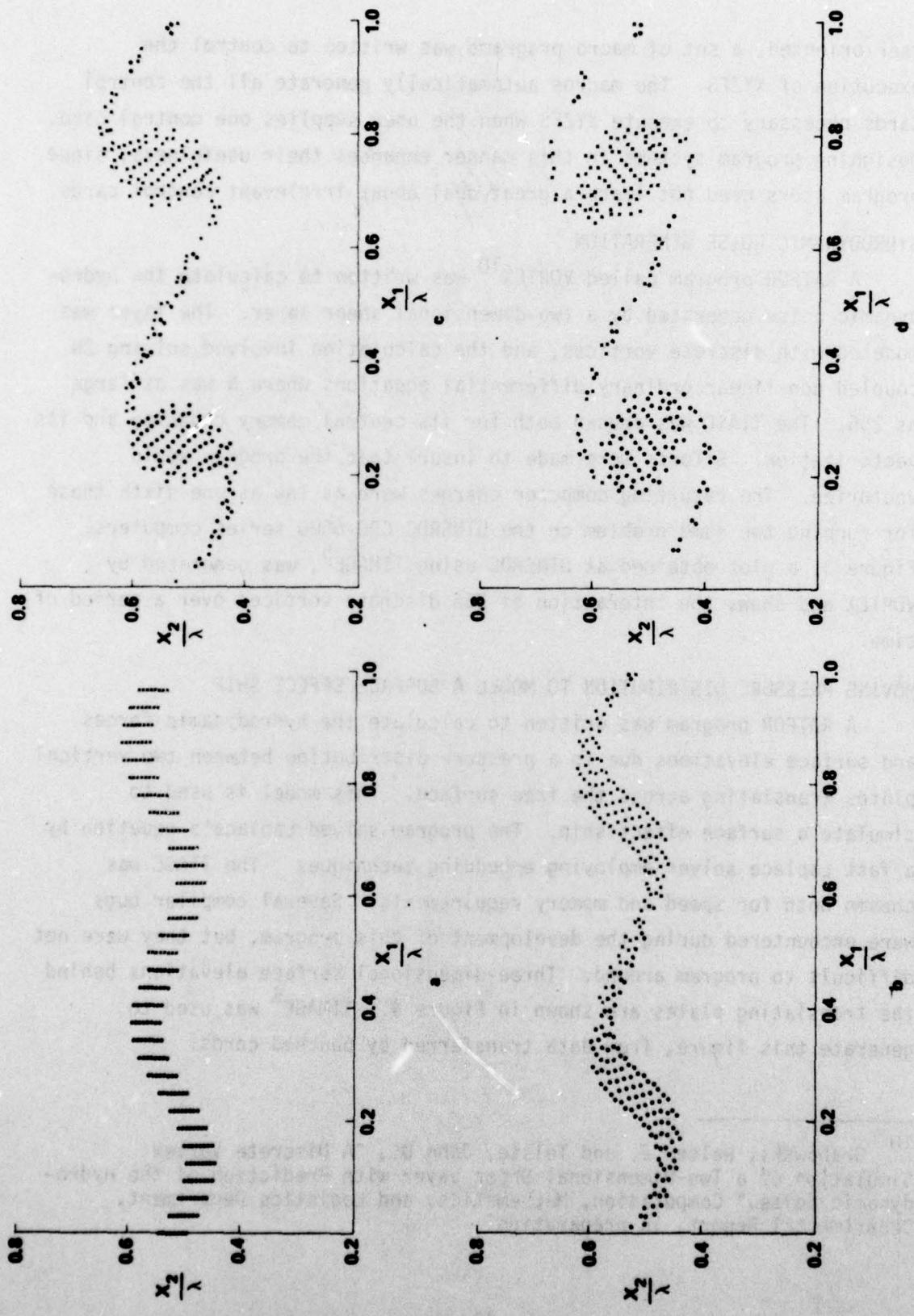


Figure 3 - Time Evolution of Discrete Vortices

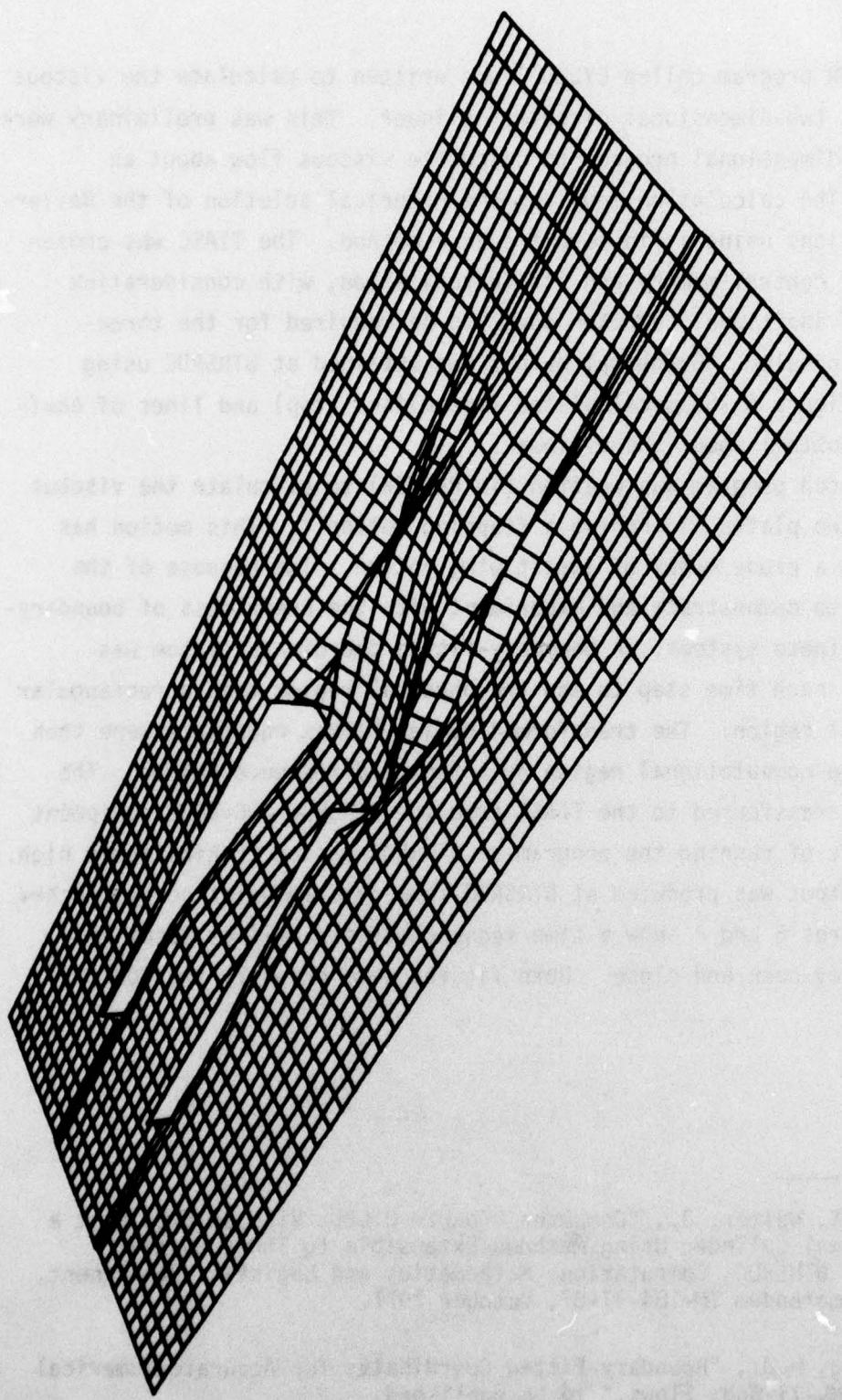


Figure 4 - Surface Elevations behind a Pressure Distribution between Translating Plates

## VISCOUS FLOW

A RATFOR program called CYL2D<sup>11</sup> was written to calculate the viscous flow about a two-dimensional circular cylinder. This was preliminary work for a three-dimensional program to calculate viscous flow about an appendage. The calculation involves the numerical solution of the Navier-Stokes equations using a finite-difference method. The TIASC was chosen for both its central memory and its vectorization, with consideration given to the additional computer power to be required for the three-dimensional problem. Graphical output was obtained at DTNSRDC using CONTOUR<sup>6</sup>. Figure 5 shows calculated streamlines (top) and lines of equivorticity (bottom) about the cylinder.

A research program was written (in RATFOR) to calculate the viscous flow about two plates undergoing a flapping motion<sup>12</sup>. This motion has been used as a crude model of insect wing motion. The purpose of the program was to demonstrate and experiment with the usefulness of boundary-fitted coordinate systems. A boundary-fitted coordinate system was generated at each time step to map the physical region onto a rectangular computational region. The transformed Navier-Stokes equations were then solved in the computational region by a finite difference method. The program was transferred to the TIASC from the DTNSRDC CDC-6000 equipment when the cost of running the program at DTNSRDC became prohibitively high. Graphical output was produced at DTNSRDC from data transferred by punched cards. Figures 6 and 7 show a time sequence of streamlines about the plates as they open and close. Both figures were drawn by the CONTOUR<sup>6</sup> program.

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<sup>11</sup> Grabowski, Walter, J., "Computer Program CYL2D: Viscous Flow Past a Two-Dimensional Cylinder Using Methods Extensible to Three Spatial Dimensions," DTNSRDC, Computation, Mathematics and Logistics Department, Technical Memorandum TM-184-77-07, October 1977.

<sup>12</sup> Haussling, H.J., "Boundary-Fitted Coordinates for Accurate Numerical Solution of Multi-Body Flows," to be published.

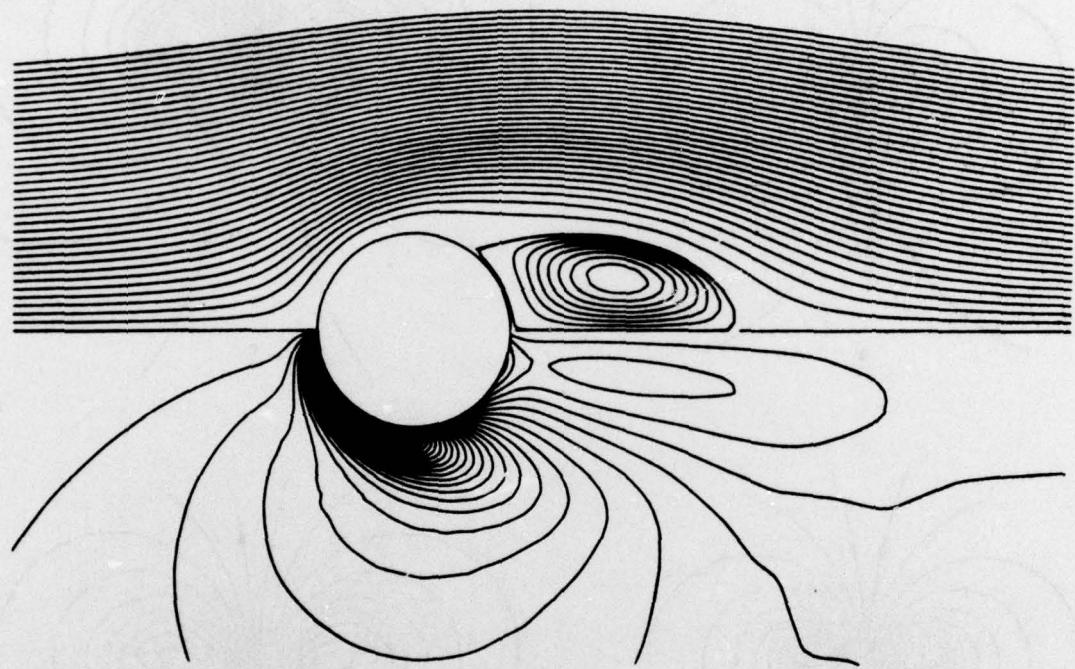
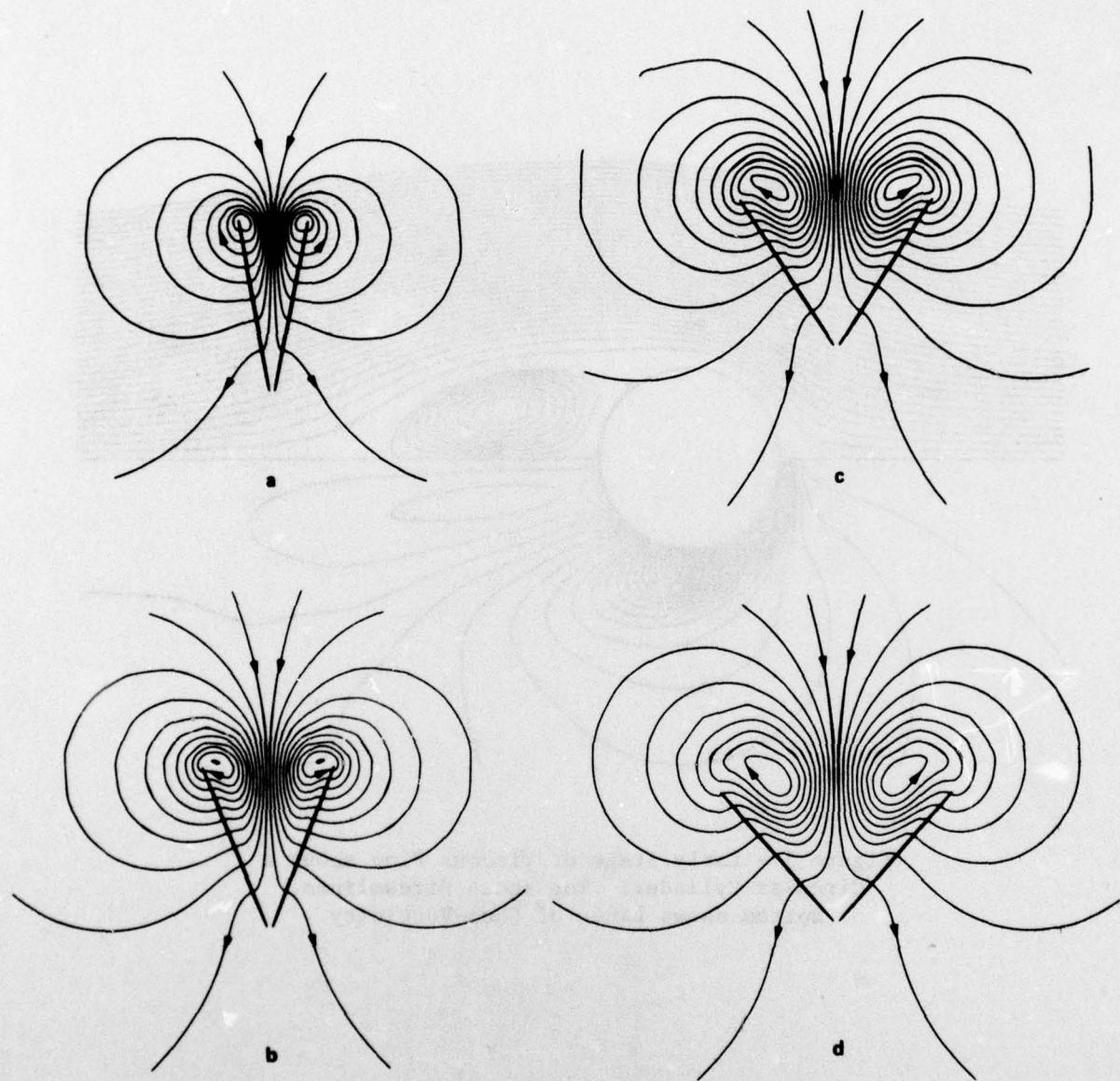
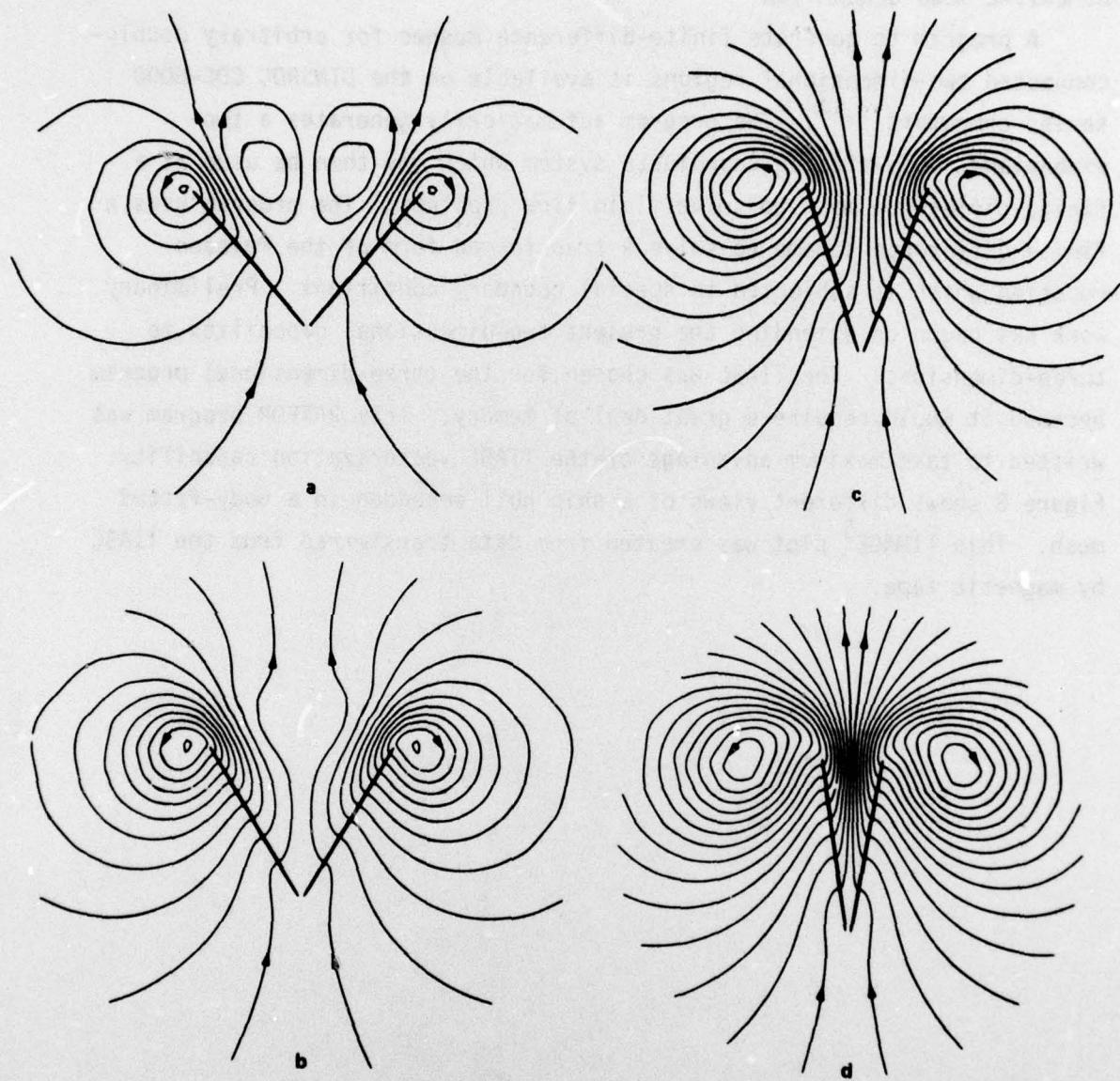


Figure 5 - Early Stage of Viscous Flow about a Circular Cylinder. Top shows Streamlines, Bottom shows Lines of Equi-Vorticity



**Figure 6 - Time Sequence of Opening Phase of Flapping Plates  
(Streamlines)**



**Figure 7 - Time Sequence of Closing Phase of Flapping Plates  
(Streamlines)**

## NUMERICAL MESH GENERATION

A program to generate finite-difference meshes for arbitrary doubly-connected two-dimensional regions is available on the DTNSRDC CDC-6000 series computers<sup>13,14</sup>. The program automatically generates a two-dimensional body-fitting coordinate system which may then be used as a finite-difference mesh to solve fluid flow problems. The program uses a finite-difference scheme to solve a transformed form of the Poisson equation which is subjected to special boundary conditions. Preliminary work has begun on extending the present two-dimensional capability to three-dimensions. The TIASC was chosen for the three-dimensional program because it would require a great deal of memory. This RATFOR program was written to take maximum advantage of the TIASC vectorization capability. Figure 8 shows different views of a ship hull embedded in a body-fitted mesh. This TIMAGE<sup>5</sup> plot was created from data transferred from the TIASC by magnetic tape.

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13 Coleman, Roderick M., "NUMESH: A Computer Program to Generate Finite-Difference Meshes for Arbitrary Doubly-Connected Two-Dimensional Regions," DTNSRDC, Computation, Mathematics, and Logistics Department, Departmental Report CMLD-77-05, March 1977.

14 Haussling, H.J. and Coleman R.M., "Finite Difference Computations Using Boundary-Fitted Coordinates for Free-Surface Potential Flows Generated by Submerged Bodies," presented at the Second International Conference on Numerical Ship Hydrodynamics, 19-21 September 1977.

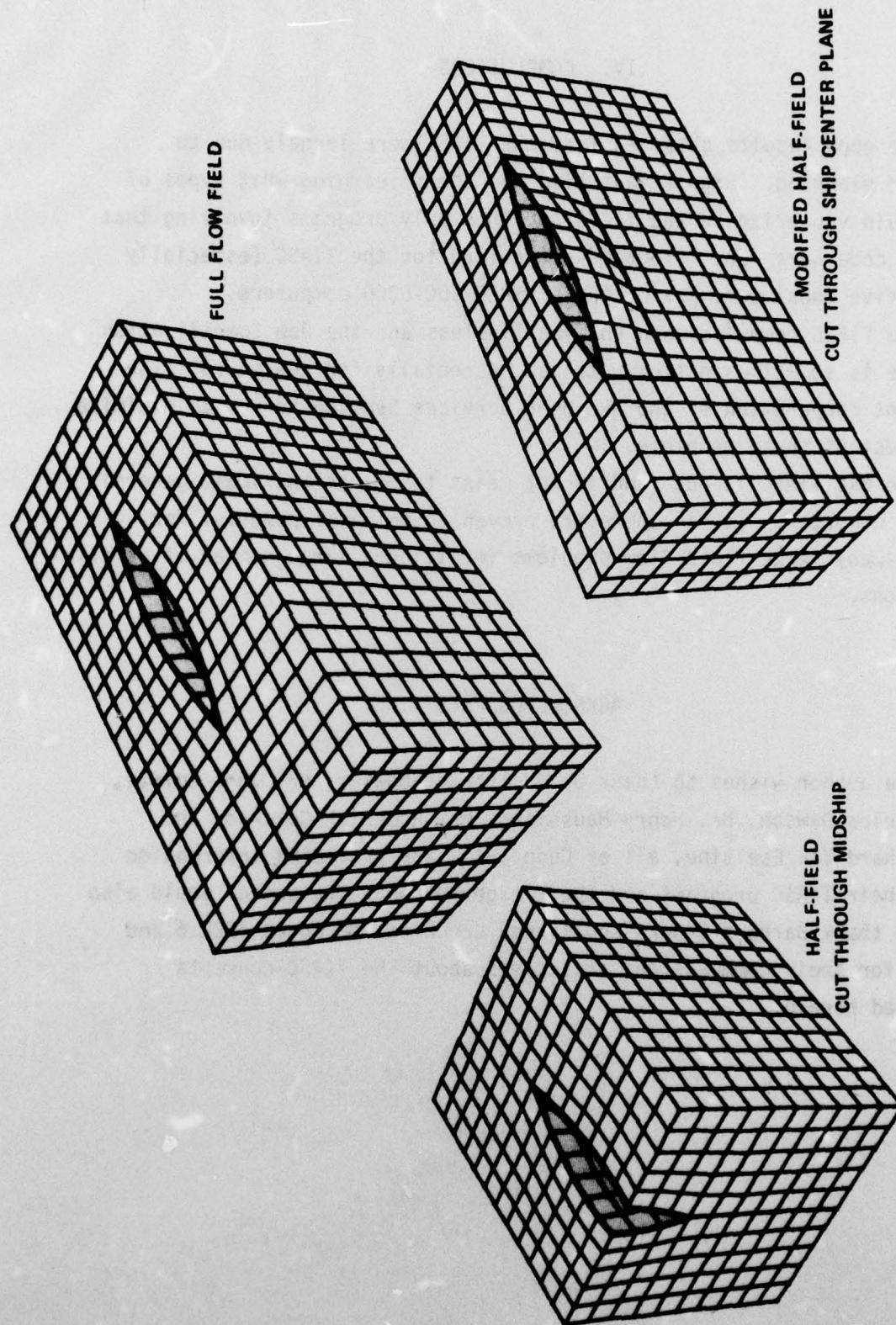


Figure 8 - Views of a Ship Hull Embedded  
in a Body-Fitted Mesh

#### IV. CONCLUSIONS

The good results obtained from the TIASC were largely due to advanced planning. Significant time was spent learning what types of code could vectorize on the TIASC and then only programs involving that type of code were run. Programs not suited for the TIASC (especially interactive ones) were put on the DTNSRDC CDC-6000 computers.

The TIASC compilers are not yet flawless and the Job Specification Language is sometimes not easy to use, especially for new users. The excellent cooperation of the NRL User Services Section serves to minimize the effect of these problems.

The NRL TIASC is not (and is not meant to be) the ultimate general purpose computer. It has, however, proven to be quite powerful for solving many large fluid flow problems involving a large number of parallel operations.

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